Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

on the mesa and in the canyons. The almost complete absence of wild game on the mesa would add to the difficulties.

The Age of the Ruins.—The lack of definite legends, among the Indian tribes of the Southwest of their relationship to these ancient Cliff Dwellers seems to indicate that these homes were deserted many hundreds of years ago, and the absence of any metals about the homes suggests the same conclusion. The relationship of this entire record to the geologic history suggests that the Cliff Dwellers inhabited this region at a time much less removed than the present from the last period of glaciation in the mountains, and the question may perhaps be raised, may we not find some evidence in the homes of these ancient peoples that will indicate that they inhabited portions of our Southwest country during the last glacial epoch in North America?

STUDIES ON CLIMATE AND CROPS*

3. THE "SOLAR CONSTANT" AND THE VARIATIONS OF ATMOSPHERIC TEMPERATURE AT AREQUIPA AND SOME OTHER STATIONS

BY

HENRYK ARCTOWSKI

At my request, Prof. E. C. Pickering kindly let me utilize for my researches on Climate and Crops the not yet published observations made at Arequipa during the years 1900-1910. As these observations interest meteorologists greatly (South American data being very scarce and not easily obtainable), I shall begin this paper by a summary of the results of my calculations.

The Arequipa station has been described previously in the *Annals* of Harvard Observatory.† The installation of the thermometers has undergone no change during the eleven years taken into consideration. The instruments were observed at 8 A. M., 2 and 8 P. M. The daily maxima and minima were also recorded. Some gaps occurring here and there were not important enough to affect the averages, except in the case of the 2 o'clock observation during the month of March 1908. The adopted value 64°.1 is therefore more or less hypothetical. The daily minima are also lacking from April 8th, 1909, till March 7th, 1910.

The lowest temperature, 36° F., was recorded in Aug. 1908 and the highest, 78° F., in June 1910.

The annual maxima are 74° or 75°, except in 1909 and 1910, when they were 76° and 78°. The lowest maximum recorded is 68° (Jan. 1904). This small difference, of only 10° between the extreme values of monthly maxima, explains why the annual maximum may occur at any time of the year. The highest yearly minimum, 42°, was observed in 1901.

---

* Paper 1 in this series appeared in *The Bulletin*, Vol. 42, 1910, pp. 270–282; Paper 2 in the same volume, pp. 481–495.

† *Annals of the Astronomical Observatory of Harvard College*, Vol. 39. Cambridge, Mass., 1899.

Table 1 gives the mean maxima and minima and also their differences for each year.

TABLE 1.

YEAR	MEAN MAX.	MEAN MIN.	DIFF.	FEB'Y	JULY
1900....	68.73	49.59	19.14	16.6	19.0
1901....	68.20	48.90	19.30	18.1	19.5
1902....	68.06	49.02	19.04	16.7	19.3
1903....	67.52	47.88	19.64	18.9	19.1
1904....	67.02	47.20	19.82	19.7	20.1
1905....	68.18	48.45	19 73	20.0	19.6
1906....	67.73	47.07	19.76	19.4	19.5
1907....	66.76	48.69	18.07	14.9	18.3
1908....	67.06	48.27	18.79	16.5	19.3
1909....	66.80	....			
1910...	66.46	....			
Mean differences =			19.25	17.9	19.3

TABLE 2.

YEAR	8 A. M.	2 P. M.	8 P. M.	DIFF. 1	DIFF. 2
1900....	60.10	66.66	54.02	6.56	12.64
1901....	59.57	66.28	53.45	6.71	12.83
1902....	59.34	66.36	53.53	7.02	12.83
1903....	59.31	65.57	52.92	6.26	12.65
1904....	58.53	65.52	52.03	6.99	13.49
1905....	59.62	66.38	53.33	6.76	13.05
1906....	59.03	66.09	52.71	7.06	13.38
1907....	58.38	64.71	52.86	6.33	11.85
1908....	58.78	65.00	52.79	6.22	12.21
1909....	58.32	65.17	51.87	6.85	13.30
1910....	58.09	64.28	52.32	6.19	11.96
Mean	59.01	65.64	52.89		

The mean difference, 19°.25, expresses the range of the daily variation slightly exaggerated.

More information on the daily variation can be obtained from Table 2, which gives the mean temperatures for the hours 8 A. M., 2 and 8 P. M.

I give these figures for each year as it is interesting to compare the differences 2 P. M.–8 A. M. (Diff. 1) and 2 P. M.–8 P. M. (Diff. 2) from year to year, with those of other stations as I have done in the case of Russian data.*

Table 3 contains the monthly means, which have been calculated according to the formula (8+2+8+8)÷4, to make them correspond to those of the maxima and minima.

TABLE 3.

STATION—AREQUIPA. DATA—MEAN TEMPERATURES.

YEAR	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1900........	58.5	59.3	60.2	59.6	57.7	57.3	56.0	58.4	58.8	59.4	59.5	59.6	58 69
1901........	59.1	59.4	58.0	58.7	58.1	55.9	56.0	58.3	59.4	58.4	57.8	59.0	58.17
1902........	58.3	57.5	57.7	58.5	58.2	56.0	57.6	57.6	58.8	58.9	59 2	59.7	58.17
1903........	60.4	61.8	58.7	57.2	56.8	55.5	56.3	56.0	58.6	58.2	56.3	56.6	57.70
1904........	57.0	57.2	56.3	57.2	55.6	56.0	55.0	57.3	57.9	57.5	58.8	58.4	57.02
1905........	58.2	59.5	57.0	58.2	58.1	57.8	56.9	57.7	58.0	59.6	58.7	58.2	58.16
1906........	59.1	58.8	58.9	59.2	57.7	55.0	55.2	56.6	58.7	57.1	58.3	56.7	57.61
1907........	56.3	55.4	58.1	56.6	57.1	56.3	55.8	57.0	58.3	58.1	58.6	58.5	57.17
1908........	58.5	57.4	(58.1)	58.2	57.5	56.8	55.5	58.3	57.5	56.9	57.9	57.4	57.50
1909........	57.2	56.4	58.7	56.7	54.7	54.1	55.8	56.2	58.7	58.0	57.3	57.5	56.77
Mean	58.26	58.27	58.17	58.01	57.15	56.07	56.01	57.34	58.47	58.21	58.24	58.16	57.70
1910........	55.8	56.1	55.2	57.6	56.3	56.5	55.4	56.7	58.0	57.2	58.5	57.5	56.73

The mean yearly variation is characteristic: From Sept. till April a temperature slightly above 58° F., June and July approximately 56°. An amplitude of only 2°.4.

* * *

In my former researches on the variations of the annual means of temperature† I showed that the changes in the geographical distribution of excess or deficit temperatures—the annual pleions and antipleions—must be due to changes of solar activity.

---

* "Notice sur les variations de longue durée des amplitudes moyennes de la marche diurne de la temperature en Russie (*Bull. Soc. Belge d'Astronomie, 1908*)."

† "L'enchaînement des variations climatiques." Bruxelles, 1909.

Moreover, having utilized all available data, for the years 1891 to 1900, I found a predominance of antipleions for 1893 and for 1900, on the contrary, pleions occupying extensive areas.

In 1900 the temperature at the earth's surface must have been at least 0°.5 C. higher than in 1893, a year of maximum of sunspots. Later, the extensive actinometrical observations of Gorczynski,* showing the depression of the solar activity during the year 1903, attracted my attention to the meteorological phenomena of that year. I therefore collected monthly and annual means of temperature, for as many stations as I could, with the intention of discussing the maps, for the decade of years 1900 to 1909, with special reference to the year 1903. But this discussion needed an introduction.

In 1903 Europe was covered by a thermopleion having its center in Russia where the temperatures were 1°.5 C. above the ten years mean. In 1902 and 1904, on the contrary, the temperatures were below the averages. The European pleion of 1903, this wave of excess of heat during a year of diminution of solar radiation, seems abnormal. But it is only a typical example of the complicated effect due to temporary diminution of the quantity of energy radiated from the sun to the earth.

Regional temperatures depend on the direction of prevailing winds, the winds depend on the distribution of atmospheric pressure, the abnormalities of atmospheric pressure depend to a great extent on the distribution of the differences in temperatures and therefore on the geographical distribution of land and sea, of clouds, ice, dust, rocks and vegetation. And to foresee, theoretically, the effects of a given variation of the "solar constant" on the general circulation of the earth's atmosphere and on the local changes in the distribution of temperature is, in the present state of our knowledge, an absolute impossibility.

To approach the simpler problem of the European pleion of 1903, I thought best to begin with the study of the mode of formation of pleions in less disturbed areas, leaving entirely aside, for the present, the dynamical problem of their mode of propagation.

The meteorological records of Arequipa, in Peru, of Bulawayo, in Rhodesia, and of Batavia, in Java, ought to give, it seemed to me, some good information on the origin of pleions.

I added Mauritius, Hawaii and Porto Rico to have records of tropical islands in the Indian, Pacific and Atlantic oceans. The other stations which I took into consideration, for the sake of comparison, are: Colombo (Ceylon), Bombay, Hong Kong, Tananarive (Madagascar), Capetown, Havana, Montevideo and Adelaide.†

---

* Ladislas Gorczynski: "Quelques renseignements sur la dépression du rayonnement solaire à Varsovie en 1903." (*Bull. Mét. du département de l'Hérault.* Montpellier, 1906.)

† The figures for Capetown, Mauritius, Bombay, Colombo and Adelaide were obtained from the mean maxima and minima published in *Symon's Monthly Magazine.*

The data for Bulawayo were sent to me by the Rev. E. Goetz, who attracted my attention to the fact that in July, 1903, the thermometers were moved from a small Stevenson screen into a screen of about 12 cubic feet.

I received the data for Hong Kong from F. G. Figg, Director of the Hong Kong Observatory, and those of Batavia from Prof. Van Bemmelen, Director of the Observatory.

The means for Tananarive were taken from the "Observations météorologiques faites à Tananarive."

The data for Havana and Montevideo were sent to me by the Directors of the Colegio de Belen and the Colegio Pio de Villa Colon.

The meteorological stations of Hawaii and Porto Rico are those of the Weather Bureau of the U. S. Dept. of Agriculture. The data for these stations were kindly sent to me by the section Directors Wm. B. Stockman and Oliver L. Fassig.

I thank most sincerely all of these gentlemen who, by sending me these data, have helped me in my work.

TABLE 4.

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	MEAN
Arequipa	58.7	58.2	58.2	57.7	57.0	58.2	57.6	57.2	57.5	56.8	56.7	57.6
Bulawayo	(68.3)	(67.2)	(67.3)	(67.4)	65.5	66.9	65.5	64.7	66.5	65.7	65.0	....
Batavia	79.5	79.2	79.5	79.3	78.4	79.7	79.7	78.8	79.2	79.2	....	79.2
Mauritius	74.0	74.3	74.9	73.9	73.2	74.1	73.7	73.6	74.1	73.5	....	73.9
Honolulu (Hawaii)	74.5	74.4	73.9	73.1	73.8	72.9	74.1	73.8	73.1	....	....	73.7
San Juan (Porto Rico)	78.5	78.9	78.3	78.8	77.7	78.4	78.2	77.7	78.5	77.8	77.6	78.2
Colombo	82.3	82.0	81.4	81.5	80.6	81.5	81.6	81.0	81.2	81.0	....	81.4
Bombay	80.8	80.8	81.9	79.8	81.1	80.2	80.4	81.2	80.3	80.2	....	80.7
Hongkong	71.6	72.1	73.4	71.5	71.6	71.6	71.8	72.2	71.8	72.7	....	72.0
Tananarive (Madagascar)	66.0	65.5	67.1	66.0	66.0	66.6	66.2	66.0	66.7	66.0	....	66.2
Capetown	62.6	62.5	62.5	61.0	61.6	62.1	61.5	61.8	61.4	62.9	....	62.0
Habana	77.0	76.1	76.8	76.6	76.5	77.4	76.1	76.5	76.3	76.3	....	76.6
Villa Colon (Uruguay)	63.3	62.2	62.6	62.8	62.1	60.8	62.4	61.5	61.5	61.5	....	62.1
Adelaide	62.8	63.5	63.4	61.9	62.9	62.3	63.7	62.3	63.0	60.9	....	62.7

I made the consecutive totals of the monthly means of temperature for these fourteen stations and it is the diagrams showing the variation of these figures that I shall compare.

Some of these diagrams (Batavia, Montevideo, Havana and Tananarive) derive from totals of °C. and have apparently smaller amplitudes of variations. I reproduce in Table 4 the annual means of all stations expressed in °F., the corresponding points on the curves being marked by vertical lines.

Let us examine the curve of Arequipa first. The 132 figures utilized to trace

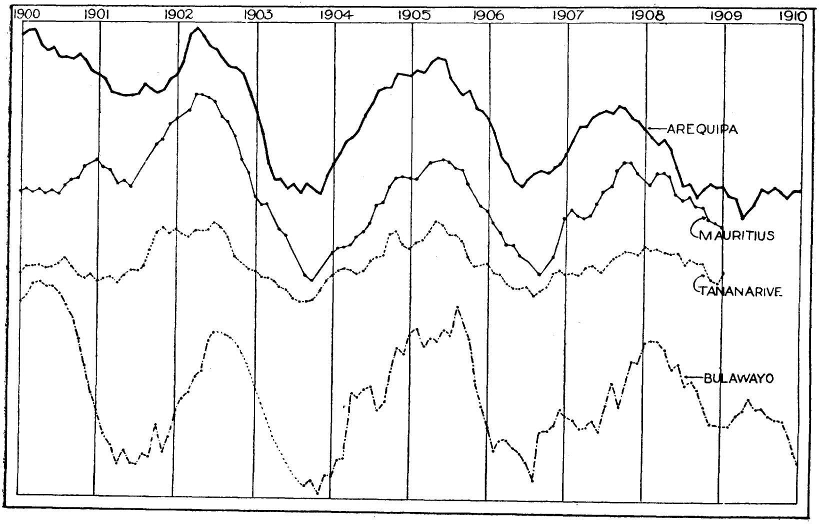

FIG. 1.

this curve (Fig. 1), being all totals of the means of twelve consecutive months, are all equivalent to yearly values. The yearly variation being therefore completely eliminated, the ups and downs of this curve are due to temporary deficit or excess of temperature independently of the moment of the year when they occurred and independently of the duration of the occurred anomaly,—the anomaly itself being expressed at the right moment when its cumulative effect on the annual mean was greatest.

The curve of Arequipa shows us three characteristic crests and four depressions. The mean temperature corresponding to the crest April 1902 to May 1903 is 58.8. The mean temperature corresponding to the depression Nov. 1903 to Oct. 1904 is 56°.7. A diminution of 2°.1 of temperature; nearly as much as the mean annual variation.*

Then the temperature rises to the crest of May 1905 to April 1906 with a value of 58°.4. The distance between the two crests is three years and one month. The following crest is nearer, the distance being only two years and four months. The distances of the depressions are also smaller than three years and they are nearly equal, the figures being thirty, thirty-one and thirty-four months.

There can be no doubt that these oscillations of temperature correspond to those of atmospheric pressure for which Lockyer† assigned a mean period of 3.8 years and which were studied for the first time by Sir John Eliot.‡

A curve of the consecutive means showing this periodicity for the temperatures observed in Batavia was published by me in Oct. 1909.§

The same curve, together with the curve of consecutive means of atmospheric pressure, was published in March 1910 by C. Braak.‖

The correspondence of these two curves is remarkable, also the variations of atmospheric pressure are in advance of those of temperature.

To return now to the question of the formation of pleions, we see that the mean temperature of Arequipa corresponding to the first crest is 1°.1 above and that of the second crest 0°.7 above the mean of the decade 1900–1909, while the departure of the depression is — 1° F.

Instead of these extreme values the departures of the yearly means of 1902, 1903, 1904 and 1905 would have been utilized to draw the maps. The figures are +0.5, 0, —0.7 and +0.5. The map of 1902 (if such a map could be drawn for Peru) would give us the pleion before its maximal development, that of 1904 the antipleion shortly after its maximal development. It is clear, therefore, that with the maps, curves of consecutive means must be utilized and that the crests are the pleions of the maps and the depressions of the curves are the anti-pleions. It is clear also that in the tropical regions pleions must be formed more or less regularly (independently of the atmospheric circulation) under the sole influence of variations of solar activity. This statement needs some words of explanation.

The sunspots, the faculæ, the prominences are manifestations of solar activity, but the only variations which directly interest the temperature of our atmosphere are those of the "solar constant." Now, these variations are more or less problematical. It is probable that such solar manifestations as the prominences and the sunspots are connected with variations of the "solar constant," but this has not yet been proven. It is therefore most interesting to notice that the temperatures observed at Arequipa show some precise correlations with the values of the "solar constant" measured at the observatory of the Smithsonian Institution.*

---

*Or even more than the range of annual variation since, according to the calculations of P. Schreiber, an amplitude obtained by the method of consecutive means (eliminating the annual period) is but 83% of its real value.

† "A Discussion of Australian Meteorology," London, 1909, and other publications.

‡ "A preliminary discussion of certain oscillatory changes of pressure of long period and of short period in India." *Indian Meteorological Memoirs*, v. 6, pt. 2, 1895.

§ " L'Enchaînement des variations climatiques," p. 32.

‖ *Meteorologische Zeitschrift*, 1910, p. 121. (Translated from *Naturk. Tijdschrift* and signed: Batavia, Oct., 1909.)

In the following diagram (Fig. 2) I reproduce the forty-four values obtained for the "solar constant" from observations made in Washington at different dates

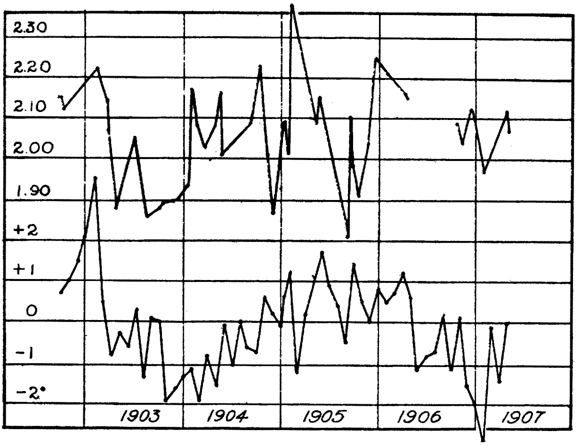

FIG. 2.

between Oct. 9, 1902, and May 14th, 1907,† and below, I have drawn the curve of the monthly departures obtainable from Table 3. It is obvious that the number of observations of the "solar constant" is insufficient to show all the details of the variation. Moreover, some measurements may have been taken precisely on exceptional days, giving values which would not have very greatly influenced results of continuous records. Special meteorological conditions may also have influenced the obtained figures.

But, taking the uncertainty of the results into account, it is astonishing to see such a close agreement between the two curves as that which is exhibited. Supposing that the fluctuations of the "solar constant" and those of the monthly means of temperature observed at Arequipa coincide, which is far from being certain, as the diagram shows that a delay is more probable, I compared the Mount Wilson measurements with the Arequipa monthly departures of temperature. To have comparable figures I made monthly means of the 121 observations taken at Mount Wilson from June to Oct. 1905 and from May to Oct. 1906.‡

The differences between these figures, compared with the differences between the departures of the corresponding months, led me to the supposition that a departure in temperature of 1° F., in a monthly mean observed at Arequipa, is due to a departure of about 0.015 of the "solar constant" from its normal value. If this is the case, we may admit that a comparably small lowering of the "solar constant," if permanent, could produce climatical changes such as those which have really existed during the pleistocene ice age. The required diminution would indeed fall entirely within the range of the momentary changes observed at Mount Wilson, the extreme values being 1.93 and 2.14 calories. But it is useless to make more far-reaching speculations, the acquired facts being sufficient to show the cause of the formation of pleions in tropical regions.

---

* C. G. Abbot and F. E. Fowle: *Annals of the Astrophysical Observatory of the Smithsonian Institution*, Vol. II. Washington, 1908.

† *Loc. cit.*, p. 98. ‡ *Loc. cit.*, pp. 96–97.

Considering once more the curve of consecutive means for Arequipa, we notice its striking descent from 1900 till 1909. The pleionian crests could in turn be eliminated by calculating consecutive means of groups of twelve monthly consecutive means. This method has been recently applied, with great success by Axel Wallen in the study of the variation of the level of the Swedish lake Vaener.*

The purpose of my paper being restricted to the question of the origin of tropical thermopleions, I will leave aside the interesting conclusions obtainable from the comparison of the rise or fall of curves in which the crests and depressions of short periodicity would be eliminated. Thus these deductions having been derived from the study of the records of Arequipa the question arises whether they are exceptional. They are not.

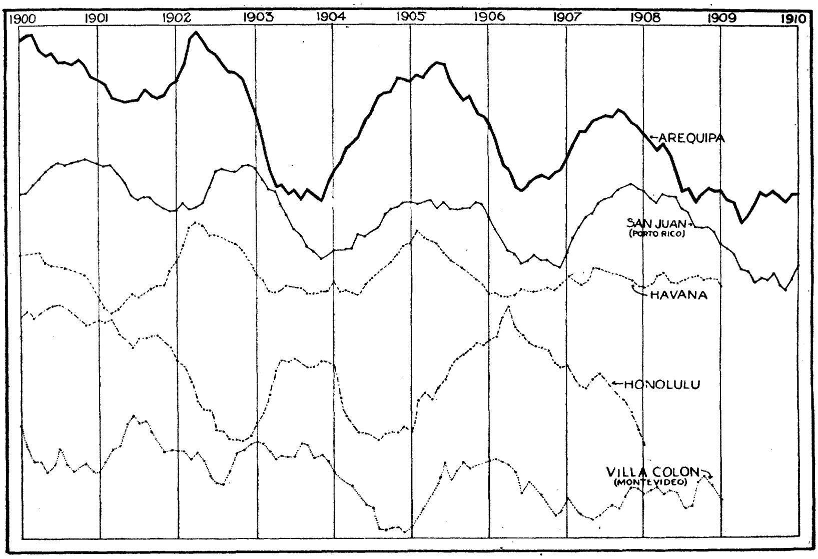

FIG. 3.

The diagram (Fig. 1) shows besides the curve of Arequipa those of Mauritius, Tananarive and Bulawayo.† The curve of Mauritius is more characteristic than that of Arequipa, the crests being more regular in shape. The amplitudes also are slightly more pronounced. But the ups and downs are practically simultaneous, and even certain small details of one curve may be observed in the other. For Tananarive the difference between the first depression and the adjacent crest is 1° C.=1°.8 F., that is to say, nearly of the same magnitude as in Arequipa. In Bulawayo the difference between the depression of 1904 and the crest of 1905 is 2°.6, therefore 0°.5 F. higher than in Arequipa. If we take into consideration the fact that Bulawayo has an absolutely continental but tropical climate and that the climate of Mauritius is oceanic, it is astonishing to see how similar the curves are.

---

* *Meddelanden från hydrografiska byrån.* 1. Stockholm, 1910.

† For Bulawayo I omitted the totals corresponding to the change of installation of the thermometers and shifted the curve of 1900–1902 downwards.

Diagram 3 reproduces the curves of Porto Rico, Havana, Hawaii and Montevideo, together with that of Arequipa, to make the comparison easier. The identity of the curves of Porto Rico and Arequipa is striking. In Porto Rico the amplitudes are smaller. In the case of the cited crest we have only a difference of 1°.2 F. And then the most interesting fact is that the curve seems to have been shifted to the right, in other words the same variations occur in Porto Rico a few months later than in Mauritius, Bulawayo or Arequipa. The tropical pleions have to travel towards Porto Rico, they do not originate there. The curve of Havana is an ascending curve. This is perhaps why the depressions are flat. The crests occur sooner than in Porto Rico, being simultaneous with those of Arequipa; but the variation is far from being as characteristic as in Arequipa.

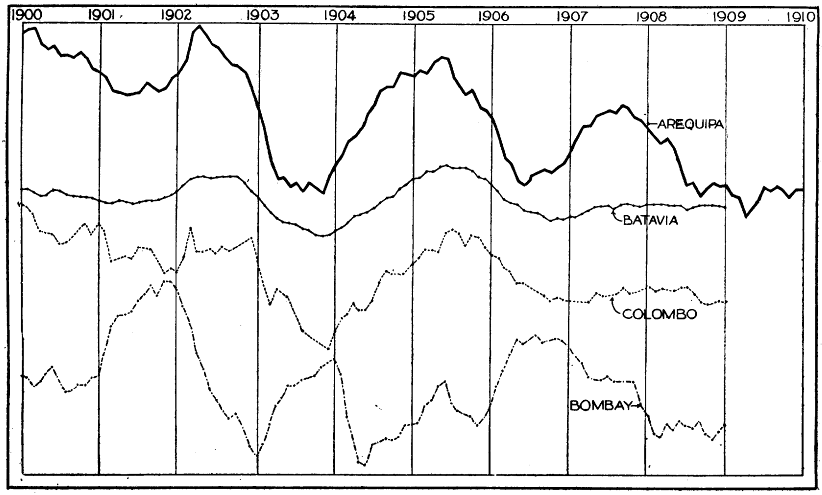

FIG. 4.

Hawaii, in the same latitude as Porto Rico, shows a totally different variation. The curve is inverted. This may be due to an increase or decrease of the trade winds due to a stronger or feebler appeal from the equator. I will leave this question without an answer simply because it would require a special investigation for which I do not possess at present the necessary material of meteorological observations. The curve of Montevideo is still more irregular than that of Honolulu and must, therefore, also be left aside.

Diagram 4 shows the similarity of the variations at Colombo and Batavia. Both curves belong to the type of Arequipa, but they are far from being as perfect illustrations of the solar action. They are, indeed, to a certain extent transitional forms between the curve of Arequipa and the curve of Bombay, which is of the opposite type. If this curve is shifted towards the left, the correspondence of the crests of Arequipa with the depressions of Bombay is very well marked. However, the character of the opposition is more complicated than in the case of Honolulu, because small crests appear in the depressions, just where they ought to be if slightly retarded, as in the case of San Juan. Another interesting peculiarity is shown on the curves of Batavia and Colombo. The crest of 1902-1903 is flat at the first and depressed at the second station. We see now how a change of temperature in one region influences those occurring simultaneously in another region. The curves of Cape Town, Adelaide and Hong Kong illustrate this fact. Here nothing or nearly nothing is left of the simply solar variation of Arequipa or Mauritius, Bulawayo and other stations.

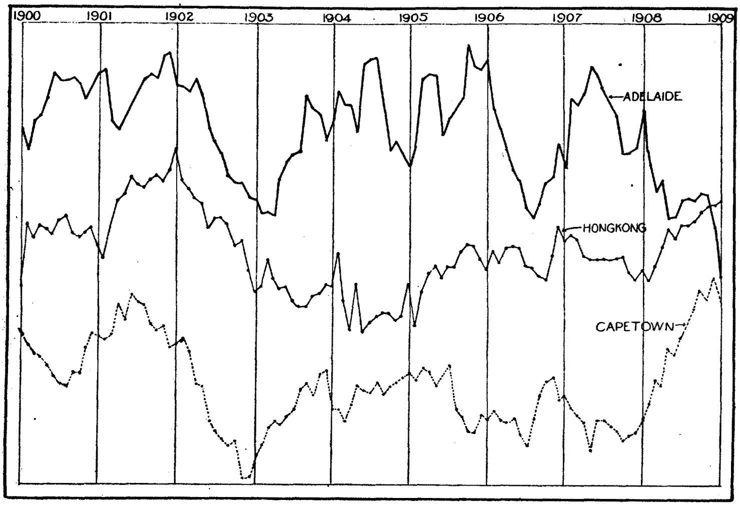

Fig. 5.

In temperate regions the rise and fall of the "solar constant" seem not to affect the temperature of the atmosphere. But this is impossible; and indeed there the climatical changes are more important than under the equator. The reasons why are still to be found. In my "Enchaînements"* I said that the maps of yearly departures for Russia demonstrate the fact that Europe must be considered as a region of travelling pleions, showing the probability of interferences of climatical waves coming from two or more centers of origin. The maps for North America also demonstrate this fact, but those of Australia are very much simpler. The variations of the "solar constant" which have such a marked effect on the temperature of the tropical regions must have an even greater effect on the temperature of the polar regions. At the pole the sun shines continuously during half a year. In the case of the inland ice of Greenland we may therefore expect an important reaction on the Islandic "center of action" of the North Atlantic atmospheric circulation. In the case of the antarctic ice cap, the effect on the sub-antarctic cyclonic system must even be greater.

Dobbs Ferry, N. Y., May 25, 1912.

---

* P. 131.